[0002] The present invention relates to optical instruments which process wavelengths of electromagnetic radiation to produce an interferogram. More particularly, the present invention relates to instruments (e.g., Fourier transform spectrometers) that produce interferograms of a scene, which instruments include an optical system which both splits the incoming wavelengths and spectrally disperses them to produce two sets of spectrally dispersed beams. The dispersion is achieved by a matched pair of gratings positioned outside the interferometer optics. U.S. patent No. 6,687,007 B1 ~~Application Serial No. 09/736,916~~ discloses embodiments wherein the matched pair of gratings is positioned inside the interferometer optics.

[0014] It is an object of the present invention to provide Fourier transform spectrometer which has all the advantages of the spectrometers disclosed in U.S. patent No. 6,687,007 B1~~application Serial No. 09/736,916~~, but which is: (a) easier to construct; (b) works in all wavelengths, including infrared and, particularly, long wave infrared (approximately 8-12 microns); and (c) has an increased optical throughput.

[0023] Finally, the interferometer optics includes a novel beam splitter including an optically transmissive element having first and second surfaces. The first surface is divided into first, second and third zones. In each of these zones, the percentage of light that is either reflected or transmitted is described as substantially for the reason that no optics can be perfect. While there will be an extremely minimal amount of loss inherent to the optics, high quality parts can reduce this loss to, in some cases less than .1% of the total wavelengths incident. The first zone has a first coating which, for the wavelengths being split, is substantially 100% reflective. The second zone has a second coating which is allows for substantially 50% of the wavelengths to be reflected and 50% to be transmitted. The third zone is substantially 100% transmissive. The second zone is between the first and the third zone. The second surface may have an anti-reflective coating. The first and second surfaces are parallel. The novel beam splitter design can be used with or without the dispersive gratings of[[~~or~~]], for instance, the present invention.

[0030] Figure 5 is an additional partial optical schematic of the ~~second~~ first embodiment of the present invention, particularly illustrating the novel beam splitter of the present invention and the transmitted portion of the beam.

[0033] With reference to Figure 1, Fourier transform spectrometer 11 processes an incident light source 13 through an aperture 15, to a beam splitter 17, where source 13 is divided into a reflected beam (represented by central ray path 19) and a transmitted beam (represented by central ray path 21). The portion of source 13 represented by path 19 is reflected from the front surface a first mirror 23 to the front surface a second mirror 25, and then back to beam splitter 17. The second, transmitted portion of source 13 is reflected off second mirror 25, back to first mirror 23 and through beam splitter 17. Thus, beam splitter 17, together with mirrors 23 and 25, serve to split incident source 13 into two portions. Spectrometer 11 also includes a detector 27 which is placed at the back focal plane of spherical (Fourier) lens 29. (Aperture 15 is in the front focal plane.) A second, cylindrical lens 31 is interposed between detector 27 and spherical lens 29, which images spatial locations from 15 onto detector 27. As is well known in the art, spherical lens 29 and cylindrical lens 31 may be assembled from one of several optical elements in various sequences to minimize optical aberrations. As is well understood in the art, this basic arrangement produces an interfering light pattern or fringe pattern at the focus of spherical lens 29, commonly referred to as an interferogram. Cylindrical lens 31 images the relative physical distribution of source 13 as selected by aperture 15 such that as it impinges on detector 27 it [[~~and~~]]represents the relative spacing for the various sources and their locations in source 13. The detector 27 is a charge-coupled device, or CCD. Alternatively, any photon counting array noise limited device, or other means of recording the optical signature, may be used. For an electric device, the output of detector 27 is processed by a computer 33 using Fourier transform techniques as is well known in the art to resolve the spectrum detected by detector 27.

[0034] To correct the problems inherent in the interferometer of Okamoto et al., and achieve the objectives set forth above, a pair of matched gratings is incorporated into the interferometer of the present invention. Thus, with reference to Figures 2 and 3, matched gratings have been integrated into the conventional interferometer design. Figure 2, spectrometer 41, includes an aperture 43, first and second matched gratings 45 and 47, beam splitter 49, first mirror 51, second mirror 53, lens system 55 and detector 57. For grating pair 45, 47, the choice of grating pitch, grating order, etc., is determined in the manner set forth with regard to, for instance, the embodiments of Figures 2 and 3 of U.S. patent No. 6,687,007 B1~~copending application serial No. 09/736,916, filed December 14, 2000~~. Beam splitter 49, is, in this embodiment, of conventional design. Mirrors 51 and 53 are typically first surface mirrors. Beam splitter 49, together with mirrors 51 and 53 is sometimes referred to as interferometer optics 59. Lens system 55 is of the conventional Fourier lens/cylindrical lens combination used to image spatial locations from aperture 43 onto detector 57, as discussed above with regard to Figure 1. Further, as with the prior embodiment, the output of detector 57 is processed by a computer (not shown) using well known Fourier transform technique to resolve the spectrum detected.

[0035] In operation, incident light, represented by central ray path 61, passes through aperture 43 and onto first ~~grating~~ and second gratings 45 and 47 where it is dispersed to produce the desired amount of lateral wavelength dependant spectral spreading of the light. This is illustrated in Figure 2 of U.S. patent No. 6,687,007 B1~~copending application Serial No. 09/736,916~~. As with, for instance, the embodiments of Figures 2 and 3 of U.S. patent No. 6,687,007 B1~~copending application Serial No. 09/736,916~~, in addition to producing the desired lateral wavelength dependant spectral spreading, the use of grating pair 45 and 47 allows for an easy adjustment of the amount of lateral spectral spread in the system, without introducing any optical aberrations, because the gratings diffract light only in a plane perpendicular to the grooves.

[0037] Figure 3, spectrometer 71 illustrates an alternate embodiment of the present invention in which the grating pair is positioned after the interferometer optics. Spectrometer 71 includes the aperture 43, beam splitter 49, first mirror 51 and second mirror 53 of interferometer optics 59, and detector 57, which are identical to those depicted in Figure 2 and function to split incident radiation into two separate beams. Figure 3 also depicts lens system 85 which is the functional equivalent of lens system 55 of Figure 2. As is well known in the art, lens system 85 includes a spherical (Fourier) lens 87 and a cylindrical lens 89 and functions to recombine the split beam paths onto detector 57. As is well known in the art, spherical lens 87 and cylindrical lens 89 may be assembled from one of several optical elements in various sequences to minimize optical aberrations. Figure 3 further depicts the incorporation of first pair of gratings 73 and 75, and second pair of gratings 77 and 79. For grating pairs 73, 75 and 77, [[~~and~~]]79, the choice of grating pitch, grating order etc. is determined in the manner set forth with regard to, for instance, the embodiments of Figures 2 and 3 of U.S. patent No. 6,687,007 B1~~co-pending application Serial No. 09/736,916, filed December 14, 2000~~. The embodiment of Figure 3 of the current application differs from the invention of the prior application in that the reflected beam and transmitted beam are dispersed by separate and distinct pair of gratings. This arrangement is necessary as the beam of light is dispersed subsequent to being split. This arrangement, as in the previous embodiment, has the benefit of allowing spectral mapping to be conducted over selectable wavelengths based on the grating parameters.

[0041] Beam splitter 103 is constructed with an optically transmissive and reflective material. Beam splitter 103 includes first surface 107 and second surface 109. First surface 107 is divided into first zone 111, second zone 113, and third zone 115. In one embodiment all three zones of equal lengths along first surface 107. In other embodiments, first zone 111 and third zone 115 are of equal lengths along first surface 107 with second zone 113 occupying the balance of length on first surface 107. ~~First~~ Third zone ~~111~~115 (on surface 107) is coated to reflect substantially 100% of the incident light in a spectral bandwidth compatible with the desired operating optical bandwidth of the system. Second zone 113 is coated to partially reflect and partially transmit the incident light, normally 50% each. ~~Third~~ First zone ~~115~~111 is coated with an anti-reflective (or transmissive) coating to transmit substantially 100% of the incident light.

[0042] In operation, with reference to Figures 4, 5 and 6, incident light, represented by ray path 61 is partially reflected and partially transmitted by the coating of zone 113 on surface 107 ~~of second zone 113~~ of beam splitter 103. Figure 4 depicts the path of the reflected light as two paths as it is naturally dispersed, collectively referred to as path 117. Figure 5 depicts the path of the transmitted light as two paths as it is naturally dispersed, collectively referred to as path 119. Figure 4 further illustrates that reflected beam path 117 is reflected by mirrors 51 and 53 and is directed toward third zone 115 of beam splitter 103. Path 117 is incident upon second surface 109 of beam splitter 103 and is refracted toward the ~~first surface 107 of~~ third zone 115 of first surface 107 where path 117 is reflected back through beam splitter 103 toward second surface 109. Beam 117 is refracted upon exiting beam splitter 103 toward lens system 121 where it is focused upon detector 57. The angles of refraction, as is well known in the art, can be calculated by standard methodology.

[0045] In the spectrometer 131 of Figure 7, beam splitter 103 is incorporated into the invention as depicted in Figure 3. Beam splitter 103 takes the place of the conventionally designed beam splitter 49, and the disclosure of Figures 4, 5 and 6 is incorporated into the description of Figure 7. The embodiment of the invention as depicted in Figure 7 has multiple advantages over the prior art. First, it incorporates the benefits of gratings being placed after the beam splitter apparatus as described with reference to Figure 3 above. Second, the new beam splitter increases the throughput of the interferometer by approximately 100% as compared to the conventional interferometer design. Grating pairs 73, 75 and 77 and 79 function in the same manner as is disclosed with reference to Figure 3 above. The choice of grating pitch, grating order, etc., is determined in the manner set forth with regard to, for instance, the embodiments of Figures 2 and 3 of U.S. patent No. 6,687,007 B1~~co-pending application serial No. 09/736,916, filed December 14, 2000~~, and will not be affected by the index of refraction of the substrate material of beam splitter 103. Figure 7 also depicts lens system 133 which is the functional equivalent of lens system 85 of Figure 3. As is well known in the art, lens system 133 includes a spherical (Fourier) lens 135 and a cylindrical lens 137 and functions to recombine the split beam paths onto detector 57.